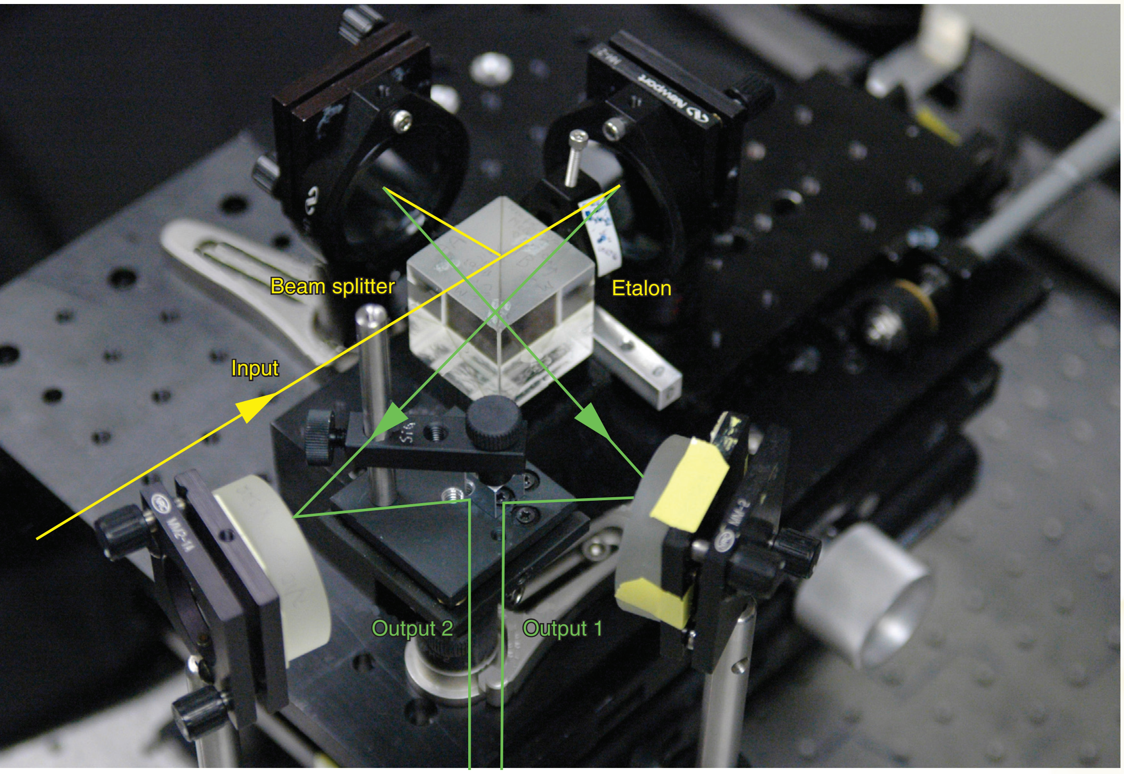
INTERFEROMETER IMPROVES

ASTRONOMERS engaged in the search for planets thrive on the occasional discovery of a new one. Spectroscopy allows them to measure small variations in the wavelength of the light received from a planet's host star. Extremely high resolution is needed to accurately record stellar spectra. Only a few observatories have the space or funding to field the multi-million-dollar, meters-long spectrographs required for this work. Observatories that do not have these resources measure stellar spectra with smaller, low-resolution spectrographs, which limit their ability to find new planets.

A new technique, called externally dispersed interferometry (EDI), allows more astronomers to join the search. Designed by Livermore physicist David Erskine in collaboration with Jerry Edelstein, an astronomer at the University of California (UC) at Berkeley's Space Sciences Laboratory, EDI achieves the high-spectral resolution needed using a much smaller and less expensive instrument. The mathematical calculation and software written for the EDI system can also be used to boost the time resolution and stability of streak cameras that record high-speed phenomena. Two projects funded by Livermore's Laboratory Directed Research and Development Program contributed to the EDI design, and this year, Erskine and Edelstein won an R&D 100 Award for developing the system.

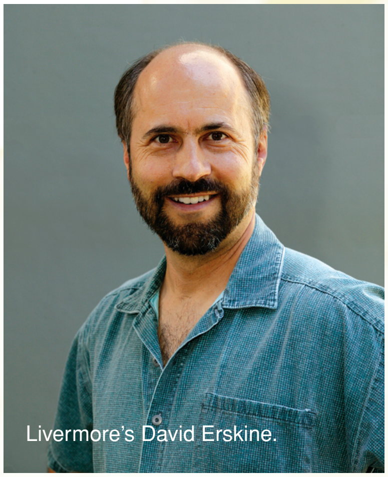
Boosting Resolution with an Interferometer

Spectroscopy relies on the Doppler effect to measure the motion of stars. The gravitational pull of a planet as it orbits a star causes a small back-and-forth wobble in the star's position and the



A laboratory-scale unit of the externally dispersed interferometry (EDI) system shows the path light takes as it enters the EDI device and is recorded by the spectrograph. The interferometer splits the light into two beams, which produce a moiré pattern that shifts in phase proportionally to changes in Doppler velocity. The etalon is a parallel plate of glass used to delay light.

Jerry Edelstein from the University of California at Berkeley's Space Sciences Laboratory.



Livermore's David Erskine.

THE SEARCH FOR PLANETS

observed wavelength of the light it emits. Called Doppler shifts, these small changes in wavelength can be measured by tracking the exact wavelength of absorption lines. These features in the stellar spectrum are like a fingerprint for the star. In conventional spectrometry, a diffraction grating disperses the spectrum across a detector, which records the absorption-line data. The pixel coordinate for each line represents its wavelength. Astronomers use these data to determine the reference star's velocity and infer the mass of the orbiting planet.

The challenge with spectrometry is obtaining the needed resolution. The width of an absorption line is equivalent to a frequency change of about 6,000 meters per second. But astronomers need to measure shifts in wavelength that are about 500 times smaller than an absorption line and about 200 times smaller than a single pixel. These subtle shifts can be dwarfed by distortions, such as air convection along the path of a star's light as it travels to Earth, or by a change in spectrograph temperature, which alters its position.

Unlike conventional spectroscopic methods, EDI boosts resolution by adding an interferometer to the measurement system. An interferometer divides the beams of light and then recombines them to force interference. Whether the interference is constructive or destructive depends on changes in wavelength so the interferometer can measure small shifts in Doppler velocity. In addition, interferometry allows scientists to process the data using mathematical equations based on only two signal paths. More complicated equations are needed to process results from a diffraction grating because it records thousands of paths.

Light entering an EDI system is split into two beams that travel separate paths. One beam travels about 1 centimeter farther than the other before the two are recombined in the output. This extra distance, called a delay, corresponds to 20,000 wavelengths of green light. Fringes—light or dark bands produced by the interference—appear in the output spectra. The moiré pattern created by these bands indicates a shift in phase that is proportional to the Doppler velocity. A Doppler wavelength shift of one part in 20,000 creates a corresponding shift in the moiré pattern of one whole fringe. As a result, EDI measurements are insensitive to spectrographic distortions. In addition, because EDI analyzes a wavelength before absorption lines are blurred by the diffraction grating, a low-resolution spectrograph coupled to an EDI system shifts the moiré pattern with the same accuracy provided by a high-resolution spectrograph.

Versatile and Affordable

A small EDI system built with commercially available optics costs about $7,000. "Many laboratories already possess a low-resolution spectrograph," says Erskine. "Adding an EDI system to an existing spectrograph is like putting on a pair of eyeglasses. It improves the system's performance severalfold and at minimal expense."

In one demonstration project, an EDI system used at UC's Lick Observatory on Mount Hamilton more than doubled the spectrographic resolution. Another demonstration improved a spectrograph's resolution by six times—far beyond the capability of the spectrograph without the EDI system.

Erskine is working with collaborators from UC Berkeley and Cornell University to design an EDI system that will operate with the Hale Telescope at the Palomar Observatory near San Diego, California. This three-year project, which is funded by the National Science Foundation, will search in the near-infrared region for planets orbiting low-temperature stars. The Gemini Observatory is also funding a study to develop a Doppler search instrument for use with the Gemini North Telescope on Mauna Kea, Hawaii.

In 2005, the EDI technique was licensed noncommercially to the University of Florida and was used with a telescope at Kitt Peak National Observatory in Arizona to discover a new planet. This planet, which lies in the Virgo constellation, is about 90 light years from Earth. It is the most distant planet to be discovered with the Doppler technique using a telescope mirror less than 1 meter in diameter.

In addition to astronomy, the EDI technique can be applied to streak cameras to improve the data obtained on high-speed phenomena, such as shock-wave experiments conducted at Livermore's National Ignition Facility. Other potential applications include technologies to improve meteorology, space surveillance, and national security.

Since 1995, astronomers have discovered about 160 planets near 3,000 stars using the high resolution available from large telescopes. With EDI, astronomers working with smaller telescopes can join the search for undiscovered planets. The added resolution could allow them to survey more than 100,000 stars in the coming decade.

—Gabriele Rennie

Key Words: externally dispersed interferometry (EDI), moiré pattern, R&D 100 Award, spectroscopy.

For further information contact David Erskine (925) 422-9545 (erskine1@llnl.gov).